

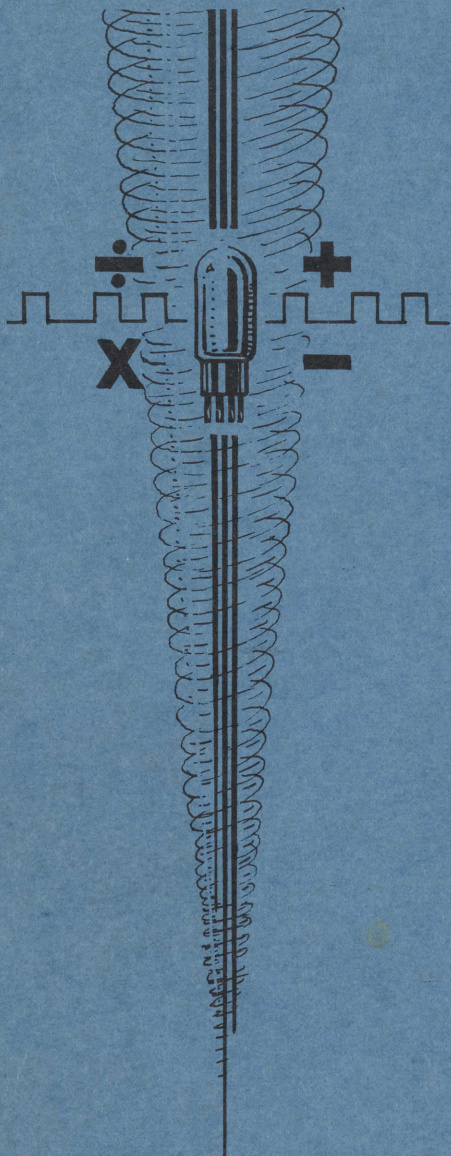
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# PROJECT WHIRLWIND

Contract N5ori60



R-142  
TALK DELIVERED BY  
JAY W. FORRESTER AT U.C.L.A.  
JULY 29, 1948

SERVOMECHANISMS LABORATORY  
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PROJECT WHIRLWIND

Report R-142

TALK DELIVERED BY JAY W. FORRESTER AT THE  
MODERN CALCULATING MACHINERY AND NUMERICAL METHODS SYMPOSIUM  
AT THE UNIVERSITY OF CALIFORNIA, LOS ANGELES.  
JULY 29, 30 AND 31, 1948.

Submitted to the  
SPECIAL DEVICES CENTER, OFFICE OF NAVAL RESEARCH  
Under Contract N5ori-60  
Project NR-720-003

Report by  
Jay W. Forrester

SERVOMECHANISMS LABORATORY  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
CAMBRIDGE 39, MASSACHUSETTS  
Project DIC 6345  
August 31, 1948

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MODERN CALCULATING MACHINERY AND NUMERICAL METHODS SYMPOSIUM  
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Project Whirlwind is a high-speed computer activity sponsored at the Massachusetts Institute of Technology by the Office of Naval Research. There are several aspects of the work to be discussed in this paper. First will be considered present work of the project in the field of digital computers. A few operating characteristics of the Whirlwind I computer now under construction will be given as well as a report on the present status of the project. Some attention will be given to test equipment which is being developed by the laboratory since these devices may be valuable to other laboratories doing work on computers. Finally, we will look briefly at some future plans of Project Whirlwind, and will examine the outlook for the future in large-scale computers.

The Project Whirlwind group considers its principal long-range objective to be research in digital computer applications, although such research does normally imply a substantial effort in the development and construction of required equipment. In the past and up to the present time the entire facilities of the Project have been devoted to the design and construction of the Whirlwind I computer. A staff of 70 with total personnel of 200 are now engaged in this work.

Digital computers show promise of almost revolutionary contributions to many branches of science and engineering, as well as to the social sciences and large-scale accounting. Although the equipment and methods being developed by the Project can be applied to most of these fields, it is necessary that the group restrict its interests to one region. This chosen region for the Project Whirlwind group is the application of digital computers to control problems. Control in this sense includes the use of computers for simulation. In control applications the computer is an operating part of a larger system. By way of illustration we might mention the control of industrial processes, military gunnery and fire control, and the centralized control of air traffic. Enough study of these problems has been completed to indicate that the more interesting control applications become feasible only with the highest speed machines which appear possible in the next few years. As a result, the Project Whirlwind work lies in the region of machine speeds of 20,000 arithmetic operations (complete multi-digit multiplications, etc.) per second. Although this speed is 10 to 100 times that of many other digital computers now being considered, the complexity of the equipment is only a few times greater. A much higher computing



efficiency, measured in multiplications per second per vacuum tube, is thereby achieved. Although required in control, it is probable that these speeds can also properly be applied to routine engineering computation.

To make this use of the enhanced computing efficiencies of the ultra-high-speed machines in computation work will require extensive studies in the administration of high-speed traffic flow and will necessitate some auxiliary equipment. High speed traffic flow will be discussed in a later section.

At the present time the principal technical sub-divisions of the laboratory are those working in electronic circuit research and design, the electrostatic storage tube group, the mathematics staff, and the block diagrams and systems planning group. These men have laid down the general outline of the computer now under construction, and have reduced most of the machine to detailed block diagrams, circuits, and production drawings.

Let us now turn our attention to this Whirlwind I computer. The machine was originally planned merely to demonstrate circuit and construction techniques. It has, however, been extended to a full-scale operating machine which is entirely suitable for studying computer applications. It has a short register length of 16 binary digits which is the minimum size necessary for a satisfactory control order. It uses the so-called single-address code for greater flexibility and programming ease. The 16-digit register length is entirely suitable for many control problems though machines of the future for this purpose might better have 20 or 24 digits. For calculations requiring a greater number of significant figures, there are special built-in facilities to permit the use of multiple-length numbers with the same ease as obtained for the single register length.

Because there exists nowhere in the world a large-scale digital computer entirely successful from the standpoint of reliability and maintenance, every effort has been made to facilitate servicing and trouble location. No attempt has been made to achieve a compact design. Electronic circuits are housed in cabinets on flat panels in two-dimensional, rather than three-dimensional, arrangement as we will see in a later figure. It is possible to apply test scopes and measuring equipment to any resistor, condenser, or circuit connection in the entire machine while the computer is in normal operation. Extensive facilities, amounting to some 25% of the entire machine, are being provided to aid in trouble location. Part of these, the marginal checking equipment, is expected to detect those components in the machine which are still operating satisfactorily but which have deteriorated from acceptable component tolerances. Most potential failures can thereby be located before creating machine failure. Several studies are in process on trouble location problems. It is anticipated that for about 60% of the machine, failures can, if desired, be identified automatically with an indication showing the particular vacuum tube circuit at fault.



Looking now at the status of Project Whirlwind, we find the first finished parts of the Whirlwind I computer arriving for installation. Certain parts of the central control are now completed and undergoing tests. The first production line shipments of completed chassis for the arithmetic element will be made from the Sylvania Electric Products factory in about eight weeks. The air-conditioning system for heat dissipation is now being installed. It is to be anticipated that some circuit troubles will be encountered and that minor corrections will be required. Initial testing and research into trouble location methods can be started as soon as the complete arithmetic element has been received this fall. Sub-assemblies for the computer will continue to arrive over the next twelve months, and it is expected that the entire machine will operate about December 1949.

The storage tubes to be used in the computer are of the beam deflection type. In such a tube positive and negative charges representing the two binary digits are stored in a rectangular array on a flat plate. Laboratory research tubes of smaller than final size have demonstrated performance which would be satisfactory for initial computer operations. However, before complete tubes can be built for machine applications it will be necessary to improve laboratory facilities and to improve certain construction techniques. A vacuum system with higher pumping speeds must be built and some additional design of electron guns is needed. It is expected that satisfactory sample tubes will be built yet this year and that pilot quantities will be constructed in the first half of 1949.

Let us now examine illustrations of a few phases of the Whirlwind work. Figure 1 is a picture of the M.I.T. Barta Building, all three floors of which are used by the computer project. Figure 2 shows the final design of the vacuum tube and connector side of the B-register of the arithmetic element. Numbers in the computer are transmitted as video pulses, one-tenth microsecond wide. All video circuits are handled through coaxial cable. For convenience and to achieve an orderly arrangement, circuits have been arranged to place connectors on the edges of panels. The reverse side of this panel is shown in Figure 3. All circuit components are laid out in two-dimensional arrangement to achieve the utmost ease in servicing. In Figure 4 is a close-up of a small section of one of these panels to show better the physical construction. All components are mounted on turret lugs, and design standards equivalent to those required for production Army and Navy equipment are used except that protection against shock and vibration is not required. One will note in this Figure that the germanium crystal diode rectifier is an important circuit element. The rectifier is used for pulse clipping and for d-c restoration of bias levels. Also shown in the Figure are pulse transformers which have been developed at the laboratory for use with circuits employing one-tenth microsecond pulses at repetition rates from zero to two megacycles. In Figure 5 are shown two experimental deflection voltage generators designed for storage tube control. These circuits decode binary numbers into deflection voltages for positioning the cathode-ray beam in electrostatic storage tubes. Two identical units, one for the



X-axis and the other for the Y-axis are used. The output of these circuits when sequenced through the 1,024 positions of a 32 by 32 array are shown in the scope display of Figure 6.

The next two illustrations, Figures 7 and 8, are included to call attention to the laboratory's test equipment program. As is well known, the available measuring equipment in any scientific field may limit the rate at which progress is possible. Just as an entirely new line of test equipment was required for radar research, likewise special equipment is required for work on computer circuits. A substantial fraction of the laboratory effort is now being devoted to development of an inter-related line of standard test equipment. With units of this equipment properly connected it is possible to obtain the variety of pulse patterns necessary for research and test work in computer circuits. As rapidly as these units are designed, descriptions of their operation are being written. In addition, there will be prepared within the next two months a discussion showing examples of how assemblies of these equipments can be arranged to meet the problems that arise in computer research. Information on this test equipment can be obtained from the Servomechanisms Laboratory and in the future it may become possible to obtain the equipment itself from the Sylvania Electric Products Company. Figure 7 shows the gate and delay unit. This is a double unit. Each section will provide a gate pulse of any desired duration between 0.5 microseconds and 2500 microseconds, or if preferred, the unit will provide a delayed pulse over the same time range following receipt of an input pulse. Figure 8 shows a variable frequency clock operating over the range of 200 kilocycles to 5 megacycles putting out pulses which are 0.1 microseconds wide and up to 40 volts high. Other units of the standard test equipment will include pulse mixers, coders, gate amplifiers, scope synchronizers, pulse standardizers, push button synchronizers, register panels, video amplifiers and probes.

Let us turn our attention to possible future plans of Project Whirlwind. Computing machine design has now reached a point where the attentions of some of the staff should be directed toward computer applications. Studies of the way computers should be used are now being started. Although the use of computers as control mechanisms may be of first interest, it is true, however, that control applications will require extensive auxiliary equipment and probably several years for development. On the other hand, one can now begin plans for applying high-speed computers to computations in science and engineering.

The reader may be surprised and may not agree, but I believe that if a high-speed computer capable of 1,000 to 20,000 arithmetic operations per second were sitting here today, it would be nearly two years before the machine were in effective and efficient operation. One would be caught totally unprepared for feeding to this equipment problems at its high acceptance rate. On the other hand, this represents but one half of a vicious circle in which an adequate national interest in computer training cannot be developed until the equipment is actually available.

Many people believe that one is not obligated to use the new machines efficiently and that their existence can be justified for occasional



use on a few problems of great importance. It seems to me, however, that the high cost, upwards of a half million dollars, and the high maintenance and operating expenses which will certainly be encountered in the next few years will force development of the administrative procedures necessary to make effective use of centrally located computers. The development of high-speed traffic through such equipment is a promising approach.

Much has been said about the new advances in mathematics which will be required to use high-speed computers, and about the problems, notably in partial differential equations, which are at the limit of our present mathematical comprehension. It has been pointed out that even with high-speed machines certain of these problems will require hours, days or weeks for a solution. On the other hand, very little consideration has been given the use of high-speed machines for those problems which are even now being solved by other means and for those problems which are mathematically well understood but are just beyond the practical limits of solution by present equipment.

We feel that the first effective use of high-speed machines will be for those problems which are straight-forward in formulation and those problems which people are now attempting to solve by presently available computing equipment. To use effectively the high-speed digital computers on such problems, it will be necessary to develop some auxiliary equipment and in particular the administrative procedures required to maintain a schedule of high-speed traffic flow. In other words, it should be possible to pass such problems through a machine just as the telegraph company transmits messages. The machine would be available to a large number of groups through wire communication facility, probably teletype initially. The persons responsible for machine operation should need pay no more attention to the nature and outcome of a computation problem than the individual employees of the telegraph company need examine, understand and criticize the contents of messages which they handle. Such a procedure would be a radical departure from present practice in large-scale computers but one no more radical than the new computers themselves. The person preparing and transmitting the problem would be fully responsible for its outcome and if improperly set-up for solution, the erroneous results would be returned for his use in correcting problem formulation. Checks and the desired level of protection can be specified in the program setup. Computing programs repeatedly used by a particular subscriber can be made a part of the computing machine program library in order that only initial data need be transmitted for the majority of routine problems.

With machines such as Whirlwind I and others now under development, no manual switching or plug-board operations are required and the set-up and solution of a problem can be completely and automatically controlled through signals received by teletype connection. This is even true down to a specification of page composition in printed results and graphical presentation for facsimile transmission. Because of the low transmission rate of teletype circuits the problems transmitted from a remote point would be collected together on magnetic tape or photographic film to permit high-speed entry into the computing equipment.



To avoid the delays and administrative difficulties surrounding present large-scale computers, such a service must be as easy for an accepted subscriber to use as present teletype. The success of the administrative organization will be measured by the degree to which such computer service can compete in problems of the size requiring but a few man-hours of hand-calculating machine operation.

As I have already mentioned, the Whirlwind I computer should be in operation by the end of 1949. During 1950 the equipment and administrative procedures for high-speed traffic flow can be worked out, and during 1951 such a problem solution network should actually become possible. On a machine operated by a research group such as the Servomechanisms Laboratory, only part of each day could be devoted to such routine traffic since the machine would be kept available during normal laboratory hours for the study of new applications. Heavy loads as they develop would be shifted elsewhere to machines established with the intention of accepting routine work.

Simultaneously with the development of high-speed traffic flow, studies of control problems will be initiated. Devices must be developed for converting mechanical motions and electrical voltages to digital quantities for machine use. Special equipment for the continuous receipt of information from teletype, from radar systems, and other forms of communication must become available before the uses of computers as control devices can be fully explored.

Let us now examine the outlook for large-scale digital computers. A great deal of unfounded optimism has and still does exist regarding the availability of such machines and the rapidity with which they can be put in service. I believe that, barring an all-out emergency effort such as went into the development of radar, large-scale computers will for several years need the sympathetic care of a laboratory crew. During these several years, personnel must be trained in the proper use of the machine. Trouble locations methods must be designed and suitable facilities provided in the machines for rapid and probably automatic location of faulty parts. Until this exploratory period has elapsed the machines will not be suitable as a packaged product for the user interested only in the results and not in the advancement of the computer art. It must be borne in mind that there is not a single machine in existence today which incorporates the most important features of the proposed digital computers. In other words, none of the present machines are designed for high-speed problem set-up through completely automatic means without the use of manual switches or plug-boards. I have indicated our expectation of operating a high-speed computer by the end of 1949, the hope of developing procedures and equipment for high-speed traffic flow by the end of 1950, and for getting this equipment into operation by the end of 1951. I doubt that this schedule will be improved upon and it is possible that even with the combined efforts of all groups in the field such a time schedule cannot be met. One must remember that by comparison a radar set is a very simple and straight-forward device, yet




hundreds of millions of dollars went into the development of this equipment. True, we are building on the results of that work, yet I believe that corresponding millions of dollars will be spend in computer development before achieving even a representative sampling of the objectives which this audience visualizes. An all-out national effort such as was devoted to radar or atomic energy would, of course, accelerate the time schedules listed. Such an accelerated program would be much less efficient in a dollar and manhour sense than the present course of action. I believe that the recent high-speed electronic trend in computers has very little engineering in common with that of the differential analyzer and the many digital computers which have proven successful in the past. We must, therefore, look upon it as a new field in its earliest stages of physical development and that it will require the same growing period as any other branch of engineering.

Furthermore, in the matter of operating personnel I believe there is a strong tendency to underestimate the size of the group which will be necessary to make reasonable use of a large-scale digital computer of the future. We have made rather careful estimates of the size group necessary to operate a computing machine at the center of the high-speed traffic network which I have already discussed. We believe that a minimum of 150 people will be required and even this assumes that most problem set-up is done at the remote point and does not fall to the responsibility of the local group.

To summarize, Project Whirlwind is directed primarily at computer applications though it will continue to carry a heavy responsibility in machine development. The problems which will receive greatest attention are those requiring high-speed machines of some 20,000 arithmetic operations per second giving high computing efficiencies. The Whirlwind I computer, assembly of which is now underway, will permit such applications and studies and will be a proving ground for trouble location methods and circuits in order that improved high-speed computers may follow. One of the first applications for high-speed computers which will be developed will probably be the high-speed traffic flow network. This is chosen first because it is one of the simpler systems applications and one which can be achieved in the near future. The lessons learned can be applied in the problems to follow. With the present size staff and expenditure rate, this objective will require some three to four years. While computers appear to be capable ultimately of accomplishing most of the functions with which they are credited, it is almost certain that they will not do so at as early a date as anticipated. Many years, and large sums of development money lie between this audience and the realization of many of their hopes.

Finally, let me say that the M.I.T. staff wishes to cooperate with other groups in all ways possible. We will be pleased to see members of this group at the laboratory and we hope that information can be interchanged to best accelerate computer progress.

- Fig. 1 FB-301
- Fig. 2 FB-471
- Fig. 3 FB-470
- Fig. 4 FB-496
- Fig. 5 FB-483
- Fig. 6 FB-494
- Fig. 7 FB-497
- Fig. 8 FB-495

  
Jay W. Forrester

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FB-301

FIG. 1



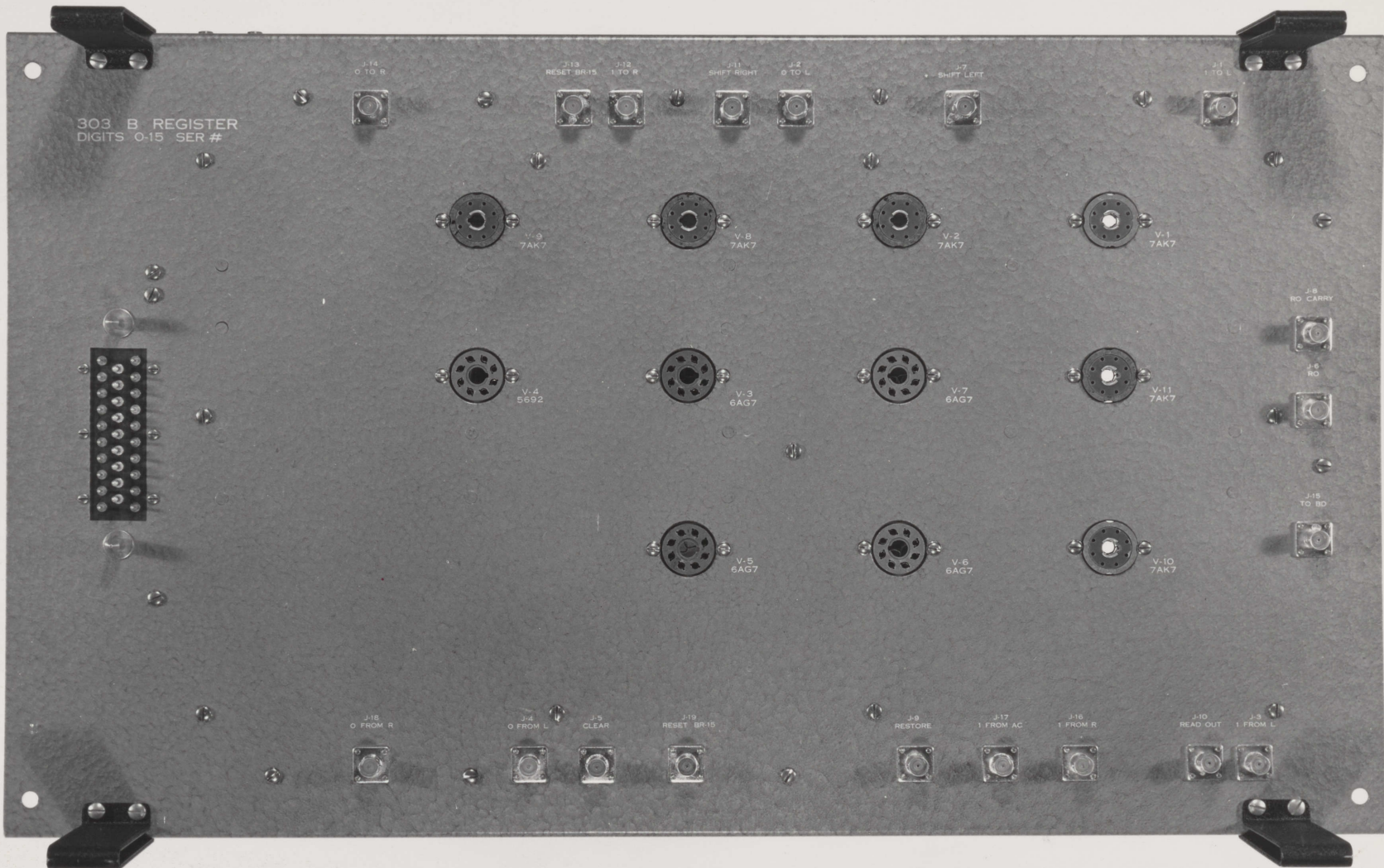


FIG. 2

FB-471



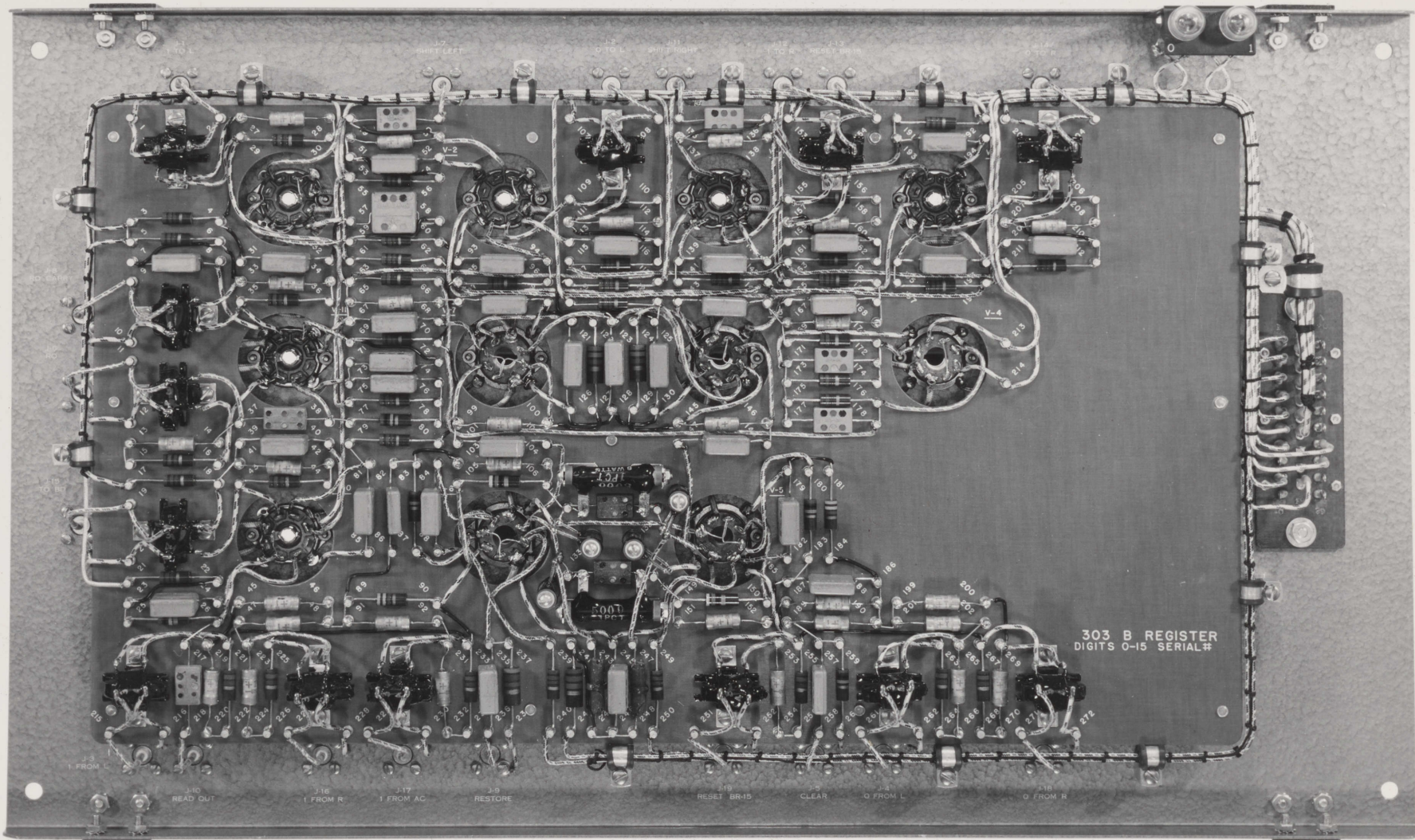


FIG.

3

FB-470



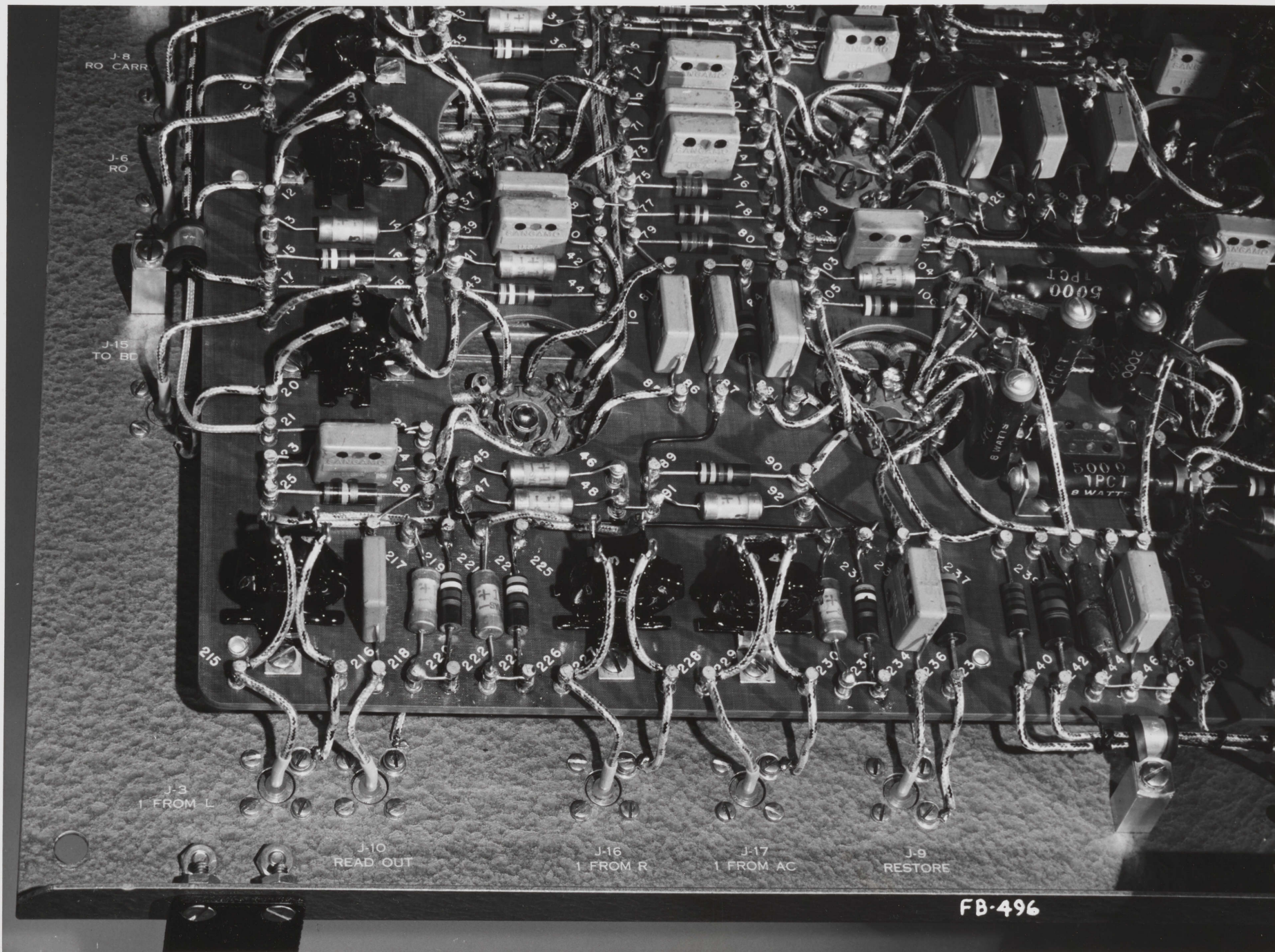
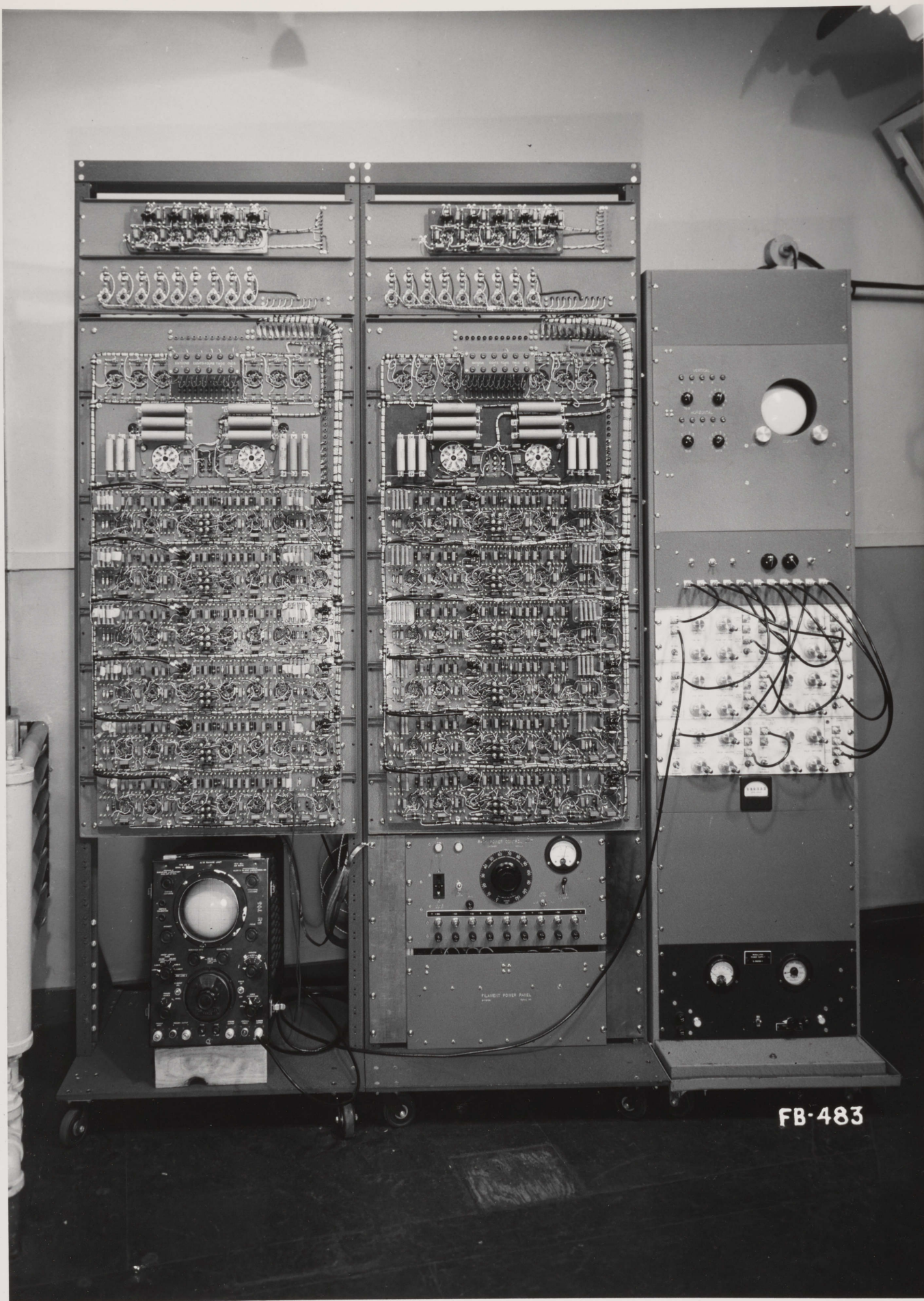


FIG.

FB-496

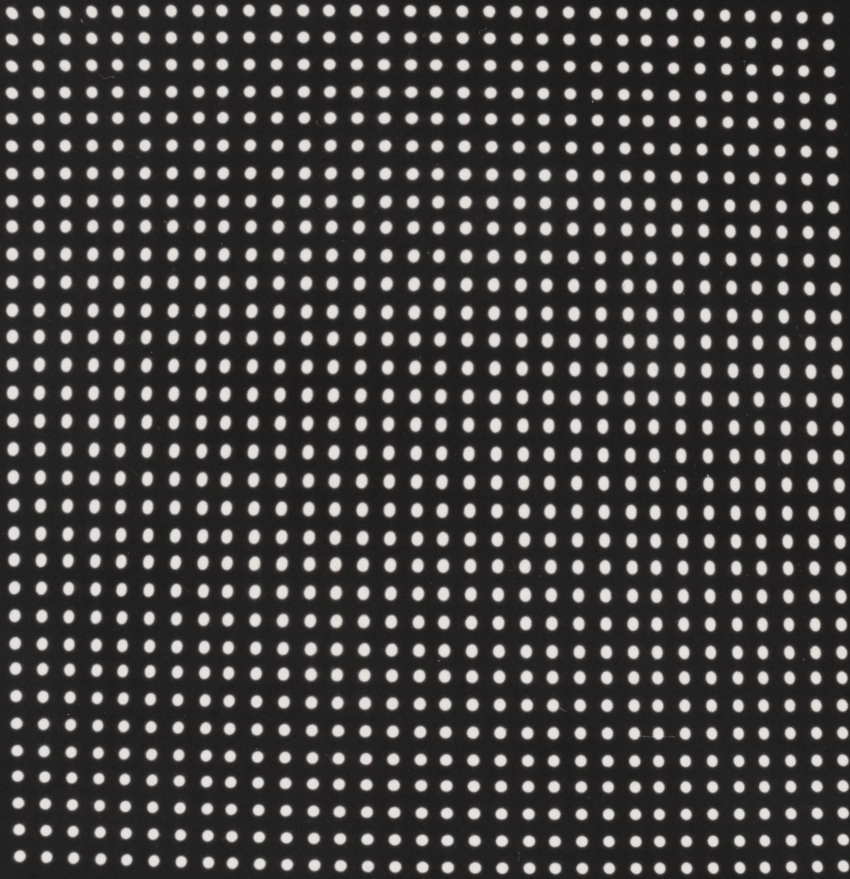




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FIG. 5





FB-494



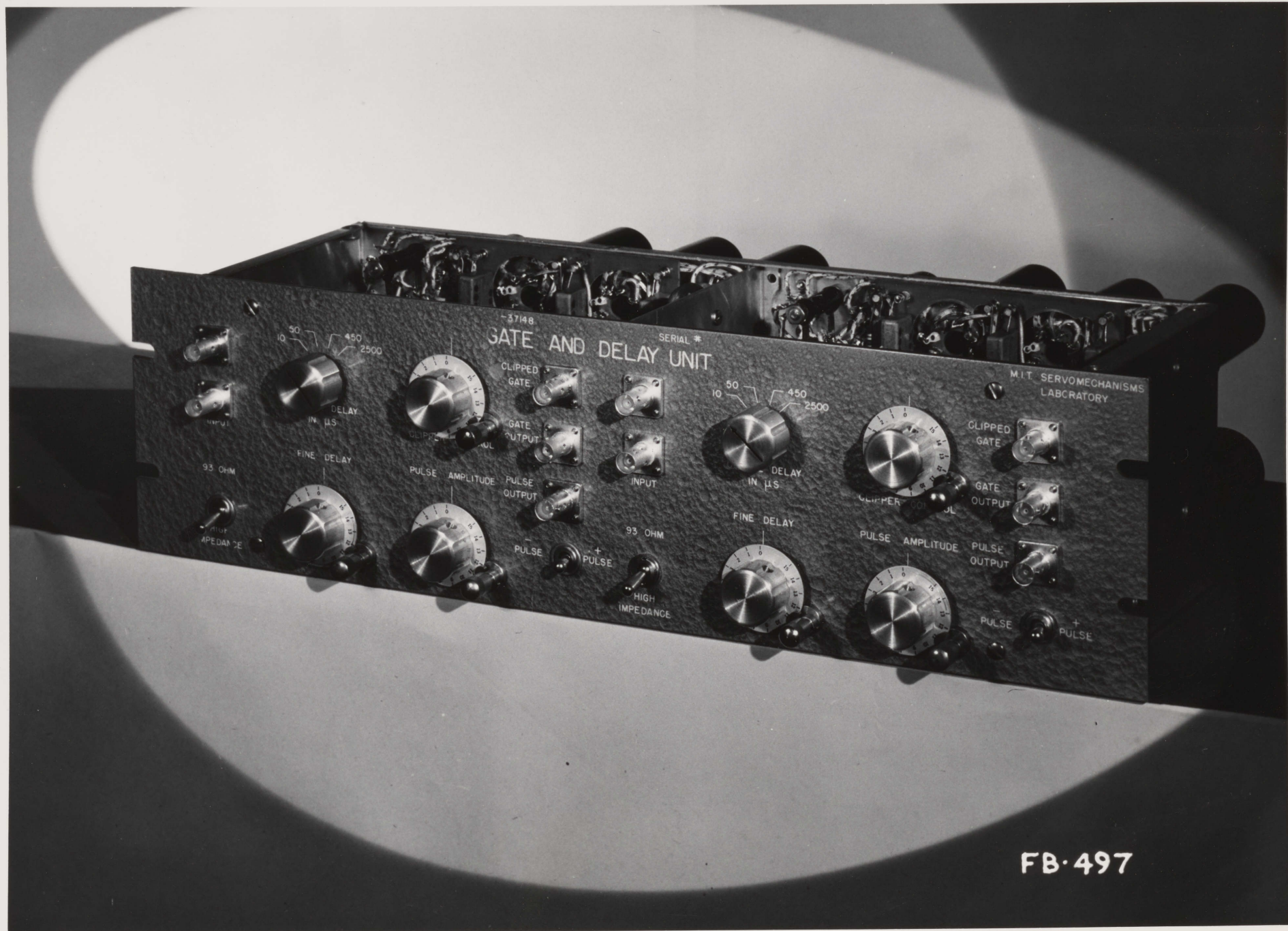


FIG. 2

FB-497



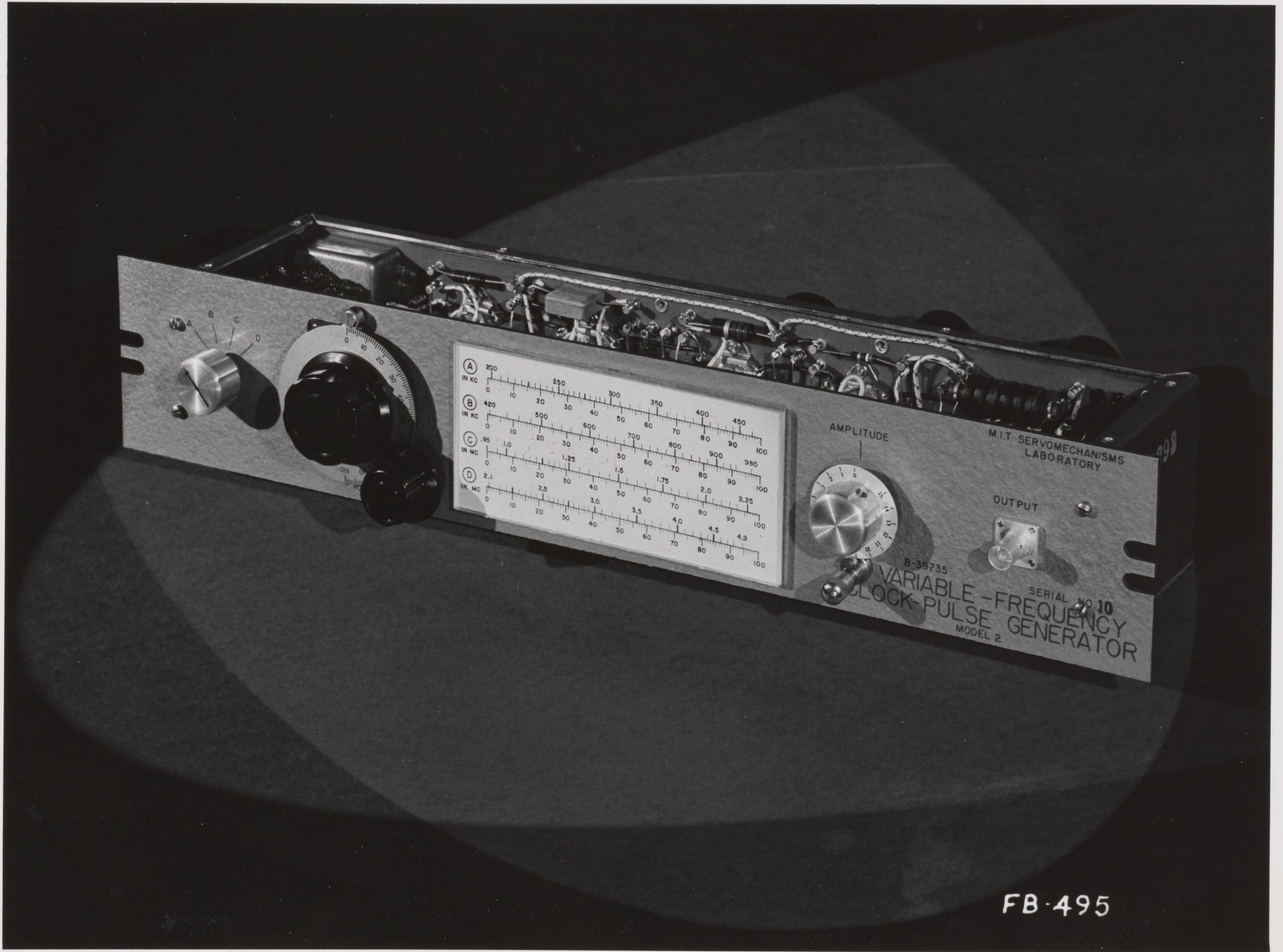


FIG. 8

FB-495







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